

Boundary conditions for the C20C Detection and Attribution Project: the All-Hist/v1 and Nat-Hist/CMIP5-v1 scenarios

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This document describes the generation of the All-Hist/v1 and Nat-Hist/CMIP5-v1 scenarios for the C20C Detection and Attribution Project. These scenarios are intended to be used by all models, providing a baseline for comparison across participating atmospheric models and for other analyses.

1 Summary

The Climate of the 20th Century (C20C) Project's Detection and Attribution (D&A) subproject is a multi-institutional effort to better characterise understanding of recent trends in extreme weather events and of the contribution of anthropogenic forcing to recent extreme events (Kinter and Folland 2011). In its first phase, the project will generate and compare simulations of dynamical atmospheric models run under observed boundary conditions (the "All-Hist" scenario) versus boundary conditions that might have been had human activities not interfered with the climate system (the "Nat-Hist" scenario).

While boundary conditions for the All-Hist scenario have been observed, and are known with some level of accuracy, the boundary conditions for the Nat-Hist scenario have not been observed and thus must be estimated. In particular, the degree to which warming of the ocean surface and retreat of sea ice coverage has resulted as a consequence of emissions is not precisely known, especially at local scales (Pall et al. 2011). Overall, the C20C D&A project will use a number of different estimates of attributable ocean warming and sea ice retreat in order to better understand the importance of this boundary condition uncertainty. For the most part the selection of estimates used will differ across atmospheric models, but in order to provide a baseline for comparative analysis there will be one common estimate used across all models.

This document describes the calculation and testing of that common estimate, referred to as the "Nat-Hist/CMIP5-v1" scenario, as well as the real-world "All-Hist/v1" reference scenario. In short, the "All-Hist/v1" is driven with observed boundary conditions at the surface, in atmospheric composition, and at the top of the atmosphere. For the "Nat-Hist/CMIP5-v1" scenario the attributable sea surface temperature (SST) warming is estimated by taking the difference between temperatures in the all-forcing historical and RCP4.5 simulations with natural-forcing historical simulations from the CMIP5 activity (Taylor et al. 2012). This attributable warming signal will then be subtracted from observed SST values, with these used to drive the atmospheric model. Sea ice coverage will be modified according to the method of Pall et al. (2011). Further details are described below.

2 All-Hist/v1 boundary conditions

The All-Hist/v1 scenario forms the set of simulations for representing the climate that has been experienced. These simulations provide data for evaluation of model performance, for estimation of changes in extreme event behaviour through time, and for reference against counterfactual "worlds that might have been" (such as the Nat-Hist/CMIP5-v1 scenario described below). The time-varying boundary conditions are listed in Table 1.

The data sets listed in Table 1 are possible selections, but other selections may make more sense for any particular modelling group and/or model. For sea surface temperatures and sea ice coverage, HadISST1 (Rayner et al. 2003) or NOAA OI.v2 (Reynolds et al. 2002) are common choices and generation of Nat-Hist scenarios will automatically include files based on these two products.

Some models may not be able to include some of the time-varying boundary conditions listed in Table 1. Anthropogenic greenhouse gases, anthropogenic sulphate aerosols, sea surface temperatures, and sea ice cov-

Forcing	Possible data source
Greenhouse gas concentrations	http://tntcat.iiasa.ac.at:8787/RcpDb/download/CMIP5RECOMMENDATIONS/PRE2005_MIDYR_CONC.zip and http://tntcat.iiasa.ac.at:8787/RcpDb/download/CMIP5RECOMMENDATIONS/RCP45_MIDYR_CONC.zip
Sulphate aerosol burden or emissions	http://tntcat.iiasa.ac.at:8787/RcpDb/download/Aerosols/AEROSOLS_1930-1969.zip , http://tntcat.iiasa.ac.at:8787/RcpDb/download/Aerosols/AEROSOLS_1970-2009.zip , and http://tntcat.iiasa.ac.at:8787/RcpDb/download/Aerosols/RCP45_AEROSOLS_2000-2039.zip
Non-sulphate aerosol burden or emissions	http://tntcat.iiasa.ac.at:8787/RcpDb/download/Aerosols/AEROSOLS_1930-1969.zip , http://tntcat.iiasa.ac.at:8787/RcpDb/download/Aerosols/AEROSOLS_1970-2009.zip , and http://tntcat.iiasa.ac.at:8787/RcpDb/download/Aerosols/RCP45_AEROSOLS_2000-2039.zip
Stratospheric ozone	http://cmip-pcmdi.llnl.gov/cmip5/forcing.html#ozone_forcing
Land cover	http://tntcat.iiasa.ac.at:8787/RcpDb/download/LUHdownload/LUHa.v1.tgz and http://tntcat.iiasa.ac.at:8787/RcpDb/download/LUHdownload/LUHa.v1_minicam.v1.tgz
Solar luminosity	http://sparcsolaris.geomar.de/cmip5.php
Stratospheric (volcanic) aerosols	http://www.pik-potsdam.de/~mmalte/rcps/data/20THCENTURY_MIDYEAR_RADFORCING.DAT and http://www.pik-potsdam.de/~mmalte/rcps/data/RCP45_MIDYEAR_RADFORCING.DAT
Sea surface temperatures	http://www.metoffice.gov.uk/hadobs/hadisst/ or http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html or ftp://ftp.emc.ncep.noaa.gov/cmb/sst/oimonth_v2/
Sea ice concentrations	http://www.metoffice.gov.uk/hadobs/hadisst/ or http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html or ftp://ftp.emc.ncep.noaa.gov/cmb/sst/oimonth_v2/

Table 1: List of time-varying boundary conditions for use in the All-Hist/v1 scenario. The suggested sources are the suggestions for CMIP5, except for the suggested volcanic forcing, sea surface temperatures, and sea ice concentrations. See <http://cmip-pcmdi.llnl.gov/cmip5/forcing.html>, <http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=download>, and <http://www.pik-potsdam.de/~mmalte/rcps/index.htm> for more information about CMIP5 forcing data sets.

Forcing	Suggested value and/or possible data source
Greenhouse gas concentrations	http://tntcat.iiasa.ac.at:8787/RcpDb/download/CMIP5RECOMMENDATIONS/PICNTRL_MIDYR_CONC.zip
Sulphate aerosol burden or emissions	At natural values
Non-sulphate aerosol burden or emissions	At natural values
Stratospheric ozone	At pre-CFC values
Land cover	At circa 1850 values
Solar luminosity	Unchanged from All-Hist/v1
Stratospheric (volcanic) aerosols	Unchanged from All-Hist/v1

Table 2: List of time-varying boundary conditions for use in the Nat-Hist/CMIP5-v1 scenario.

erage should be condition obligatory. It is preferred that the remaining boundary conditions are included, but the simulations will still be a useful contribution to the C20C D&A project in their absence.

3 Nat-Hist/CMIP5-v1 radiative forcings

Table 2 lists how the boundary conditions relating to radiative forcing differ in the Nat-Hist scenarios from the All-Hist scenario. The definition of “natural” levels is ambiguous for some drivers, such as land cover change, in which case values from the 1850-1900 era generally used to represent pre-industrial conditions can be used. While some areas of the globe had significant aerosol burdens/emissions during that era, it is still probably reasonably accurate for use in defining a natural climate. Note that there is now “natural” aerosol file corresponding to the CMIP5 anthropogenic aerosol files listed in Table 1.

4 Nat-Hist/CMIP5-v1 sea surface temperatures

4.1 Estimation of attributable ocean warming

The time-varying difference between sea surface temperatures in the real world and in the Nat-Hist/CMIP5-v1 world were calculated by subtracting skin temperatures between CMIP5 simulations following the Historical (through 2005, driven with historical changes in both natural and anthropogenic forcings) and RCP4.5 (after 2006, driven with projected changes in anthropogenic forcings only according to the RCP4.5 scenario) scenarios, and CMIP5 simulations following the HistoricalNat scenario (driven with historical changes in natural forcings only). The list of models and simulations used is given in Table 3.

The selection of these datasets was based on the following, with sensitivity tests described below.

- Selection was made based on availability on 1 April 2013.
- Models and simulations were selected based on availability of skin temperature data from simulations following the Historical+RCP45 (i.e. both Historical and following RCP4.5) and HistoricalNat scenarios.
- Combined Historical+RCP45 simulations were assembled for continuous Historical and RCP45 pairs.

CMIP5 Model	Number of simulations per scenario	Last year of HistoricalNat simulations
BCC-CSM1-1	1	2012
BNU-ESM	1	2005
CanESM2	5	2012
CCSM4	4	2005
CNRM-CM5	1	2012
CSIRO-Mk3-6-0	5	2012
GFDL-CM3	1	2005
GFDL-ESM2M	1	2005
GISS-E2-H-p1	5	2012
GISS-E2-H-p3	5	2012
GISS-E2-R-p1	5	2012
GISS-E2-R-p3	5	2012
HadGEM2-ES	4	2018/2019
IPSL-CM5A-LR	3	2012
IPSL-CM5A-MR	1	2012
MIROC-ESM	1	2005
MIROC-ESM-CHEM	1	2005
MRI-CGCM3	1	2005
NorESM1-M	1	2012

Table 3: List of CMIP5 atmosphere-ocean models used for estimating the adjustment of the SSTs for the Nat-Hist/CMIP5-v1 scenario. The same number of simulations were taken from each of the Historical, RCP4.5, and HistoricalNat scenarios. HistoricalNat simulations end in different years, depending on the model. A total of 51 simulations from 19 CMIP5 models were included in the calculation.

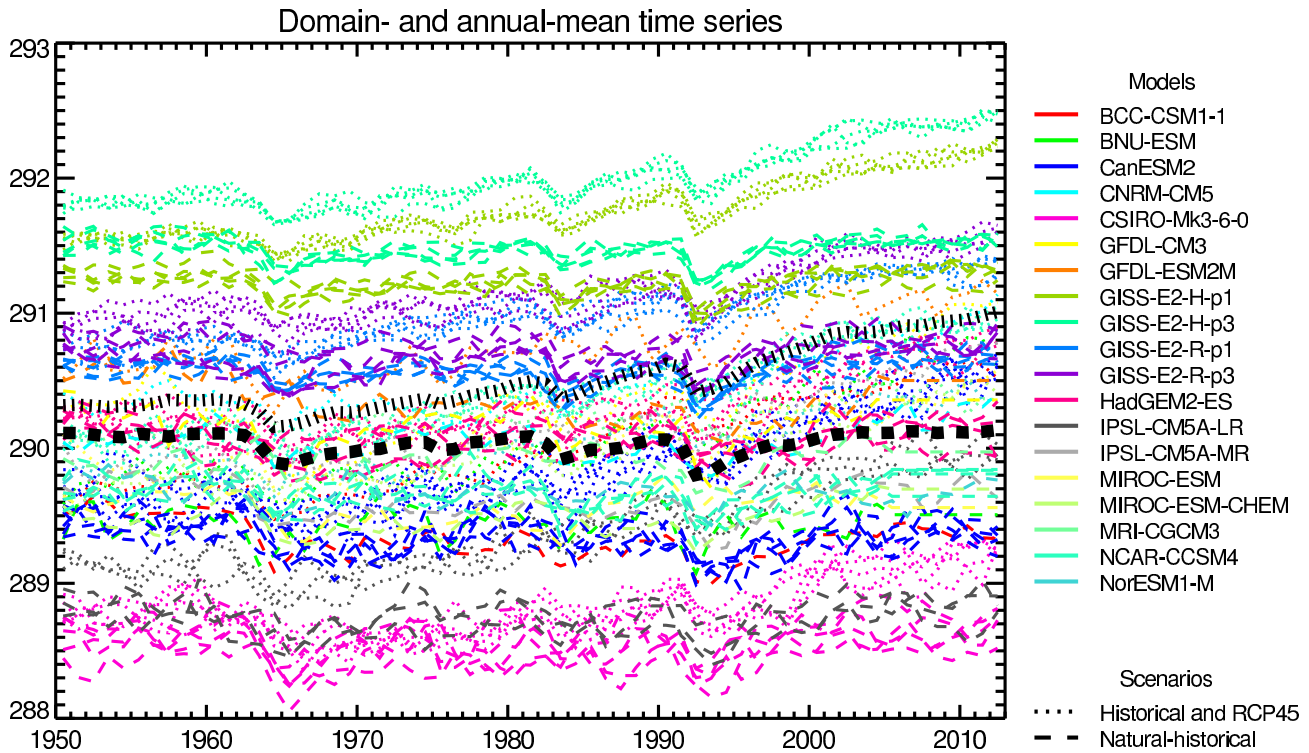


Figure 1: Annual global mean time series of skin temperature from the various CMIP5 simulations used in the calculations. Details of the models and simulations are listed in Table 3. The black lines denote the average across all 51 simulations for each scenario. No time filter has been applied for the calculations behind this figure.

- The same number of simulations per model were retained for the Historical+RCP45 scenario as for the HistoricalNat scenario.

Annual global (land and ocean) mean time series of the skin temperature data from the various simulations are plotted in Figure 1.

The following steps were followed in the calculation.

1. Skin temperature data from all simulations were loaded for the 1948-2014 period.
2. The skin temperature data were interpolated to the NOAA OI.v2 grid (1×1 degree).
3. Values were retained for both ocean and land areas, to avoid problems with different land-sea definitions across models.
4. No efforts were made to account for secular drift in the CMIP5 simulations. Assuming linearity, the drift should cancel in the difference between the two scenarios (because initial conditions for the Historical and HistoricalNat simulation pairs were ensured to be identical for each model).
5. 5-year boxcar filter was applied to the time series for each calendar month. Months without all data available for the filter period were assigned a missing value flag. The padding years are removed (i.e. the data now cover the 1995-2012 period).
6. For the HistoricalNat scenario, the values for the final available year (i.e. 2003 for simulations ending in 2005, 2010 for simulations ending in 2012) were repeated for later years (i.e. 2004 onward for simulations ending in 2005, 2011 onward for simulations ending in 2012) on the grounds that no major volcanic or solar forcing has occurred during this period. This extrapolation was not needed for any Historical+RCP4.5 simulations.

4.2 Selection of simulations and models

The estimate of the attributable ocean warming could be sensitive to the selection of models and simulations. For instance, in the procedure used here the simulation is considered the unit of input (a unit commonly used when examining past climate change, see for instance Hegerl et al. (2007)) rather than the climate model (a unit commonly used when examining projections of future climate change, for instance). Figure 2 shows the estimates of attributable ocean warming for January 2001 derived using various selection criteria. There is little difference between patterns estimated with the different criteria. Given differences between attributable warming estimates for different years (see below), the conclusion is that the advantage of greater sampling power of retaining all available simulations overwhelms any discrepancies resulting from plausible simulation selection criteria.

4.3 Selection of skin temperature

The most obvious temperature measure to use for estimate attributable sea surface warming would be sea surface temperature itself. However, because climate model sea surface temperatures cannot go below the freezing point, use of sea surface temperatures does not allow an estimate of attributable warming (and hence sea ice change) in the polar regions (Figure 3). Pall et al. (2011) used 1.5m near-surface air temperature partly for this reason, partly because of the availability of global detection and attribution studies using that variable.

Here we have decided to use skin temperature instead. This variable is readily available for the CMIP5 models, more closely matches sea surface temperature in the ice-free open ocean, and is not constrained by the freezing-point over ice-covered regions but rather represents the temperature at the ice-air interface. Over the open ocean Figure 3 shows some small differences between using near-surface air temperature and sea surface temperature or skin temperature, indicating that use of the one of the latter (i.e. skin temperature) is more appropriate.

4.4 Year-to-year variations

Anthropogenic forcing is changing only slightly from year to year, so we expect attributable warming patterns to remain fairly constant over periods of at least several years, with only an incremental change in amplitude. Figure 4 compares the attributable warming maps calculated for January 2001 and January 2006, with no temporal filter applied. The main features are similar in both years, but there remain some region differences that are substantial with respect to the overall attributable warming, for example around New Zealand.

Figure 5 shows the same plots as in Figure 4 except after a 5-year boxcar filter has been applied to January values. In other words the January 2001 attributable warming estimate is actually the average of the Januaries in 1999 through 2003, while the January 2006 estimate is the average of the Januaries in 2004 through 2006. Note for the sake of comparison that the two averaging periods do not overlap. The differences between the two years are noticeably smaller than when no smoothing is applied.

This analysis thus supports the use of some temporal smoothing.

4.5 Effect of volcanic eruptions

A notable issue however is that a temporal filter washes out the temperature response to volcanic eruptions. Compare, for instance, the CMIP5 time series in Figure 6, produced with the 5-year boxcar filter for each calendar month, against the unfiltered series in Figure 1. At the global scale it does not appear that the volcanic eruptions alter the difference in the global annual mean temperatures between the Historical+RCP4.5 and HistoricalNat scenarios in the CMIP5 simulations. But what also concerns us is whether the attribution warming pattern is altered, i.e. if nonlinearities in the climate system mean the attributable ocean warming is different in years following volcanic eruptions than from other years.

Figure 7 shows the attributable ocean warming estimates, produced without temporal smoothing, for January 1992 (soon after the Mt. Pinatubo eruption) and January 1997 (a while after any major volcanic eruptions) as well as the differences between the two estimates. There are no noticeable differences between these and the January 2006-January 2001 differences plots in Figure 4.

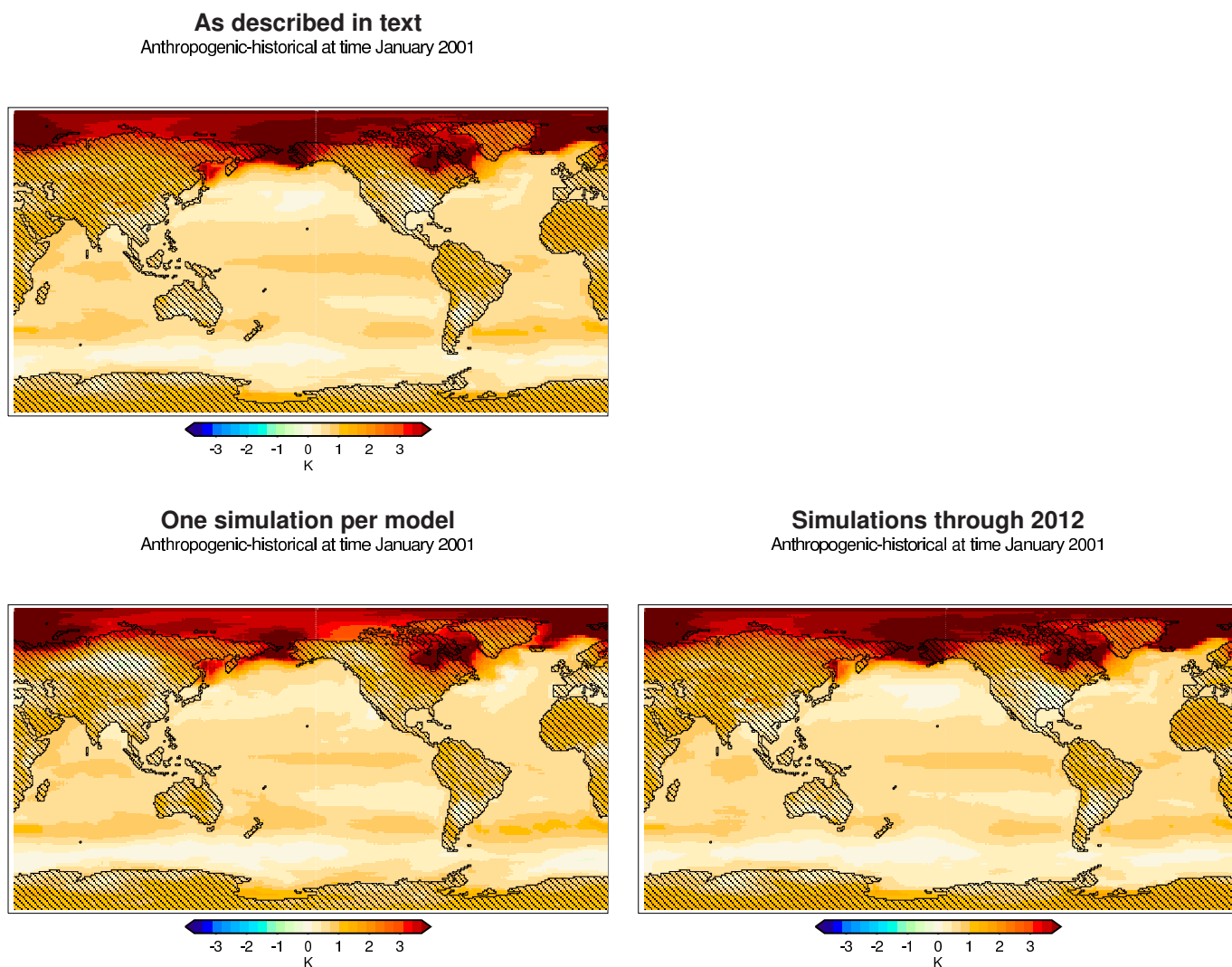


Figure 2: Estimates of attributable ocean warming for January 2001 using different criteria for selecting simulations. Top left: when all available simulations are used following the criteria described in this document. Bottom left: if only one simulation is retained per model for each scenario, resulting in 19 simulations per scenario. Bottom right: if models without HistoricalNat simulations running through 2012 are excluded. A 5-year temporal filter was used in all calculations.

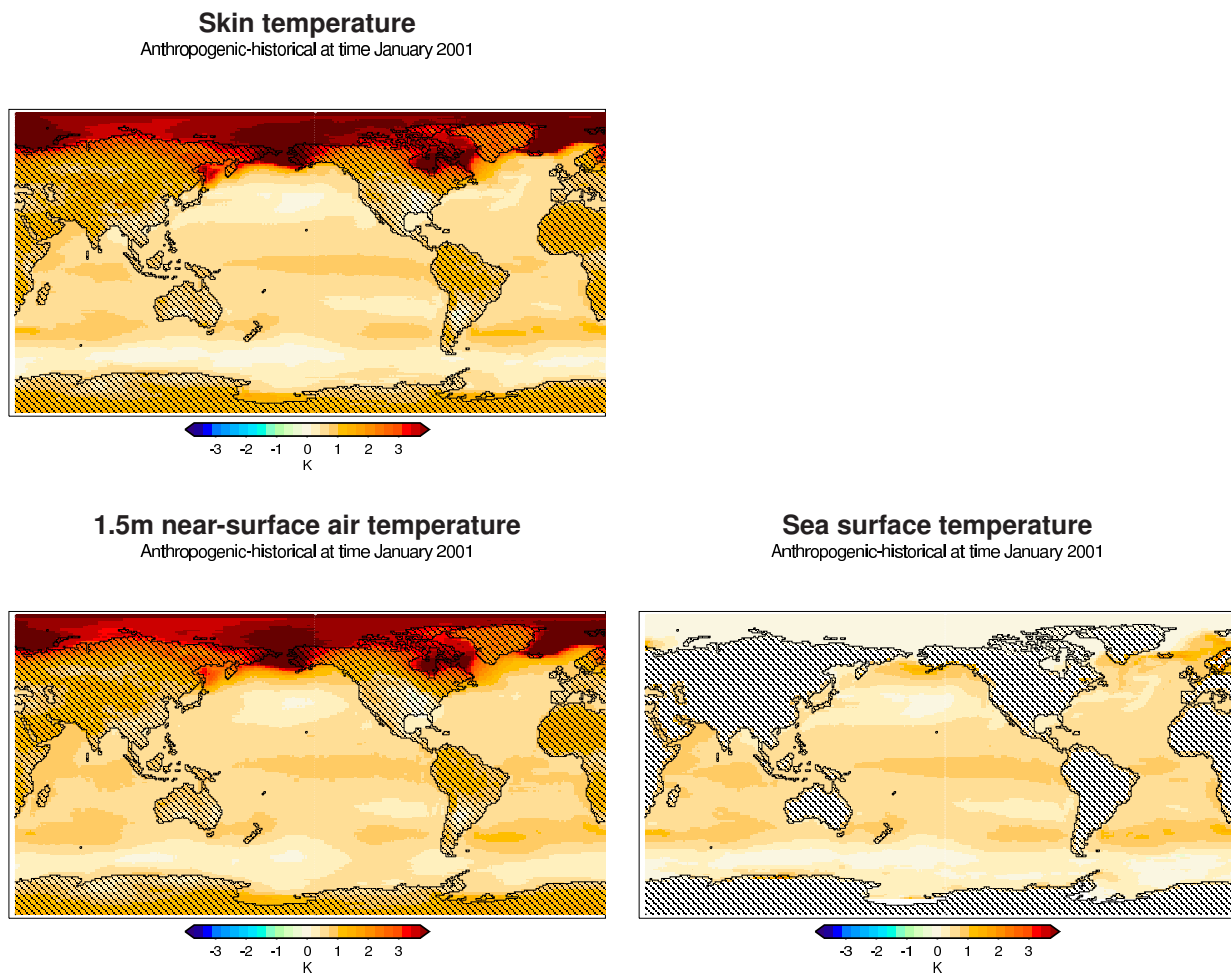


Figure 3: Comparison of estimates of attributable warming for January 2001 obtained using skin temperature, 1.5m near-surface air temperature, and sea surface temperature. A 5-year temporal filter was used during the calculations behind these plots.

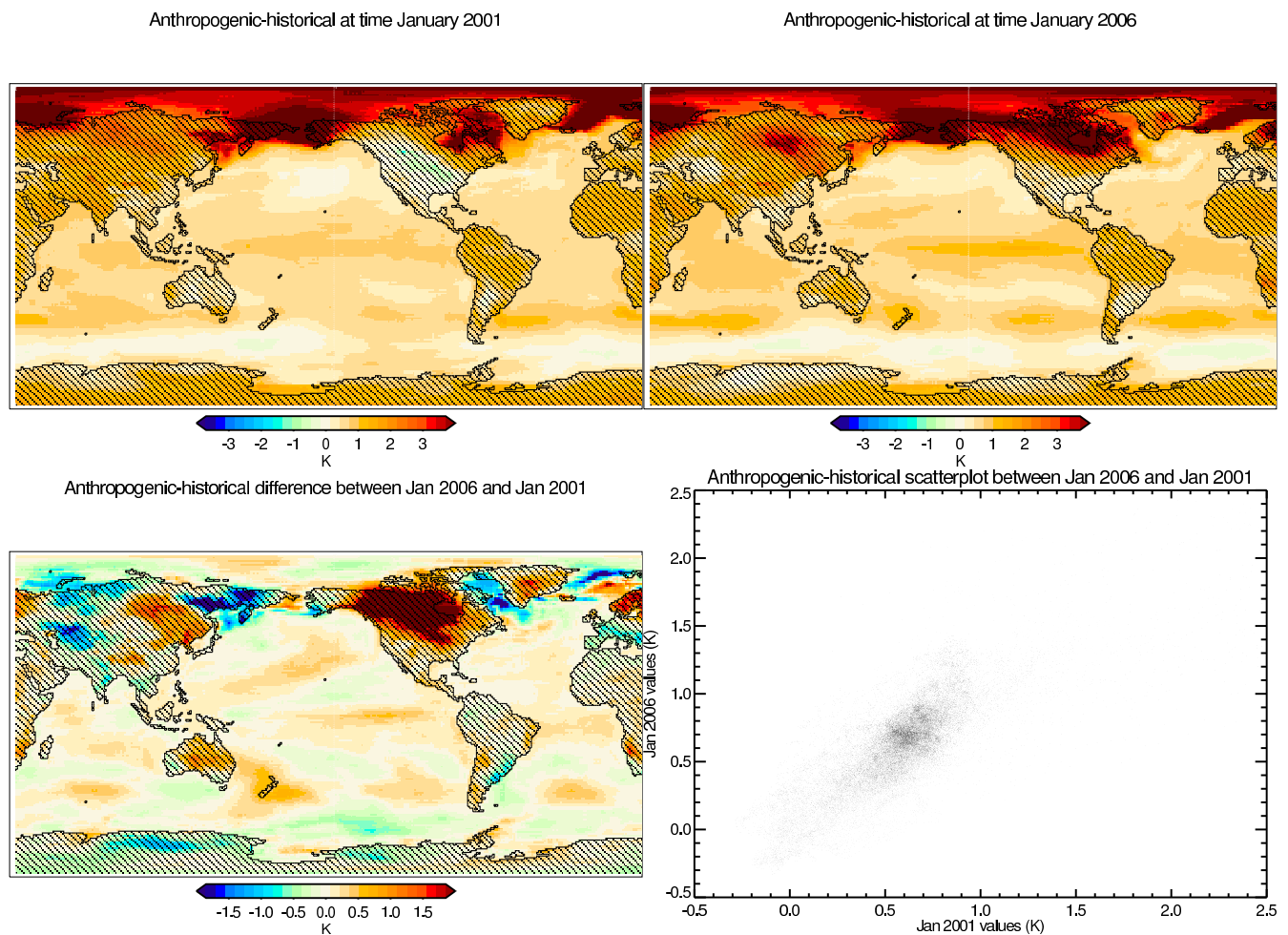


Figure 4: Maps of estimated attributable warming maps for January 2001 (top left), January 2006 (top right) and their difference (bottom left), without any temporal filter applied in the calculation. Land areas are partially masked for clarity. The plot at bottom right plots January 2006 ocean grid boxes against the corresponding January 2001 boxes. More extreme values than 2.5K (from the sea ice edge) have been cropped.

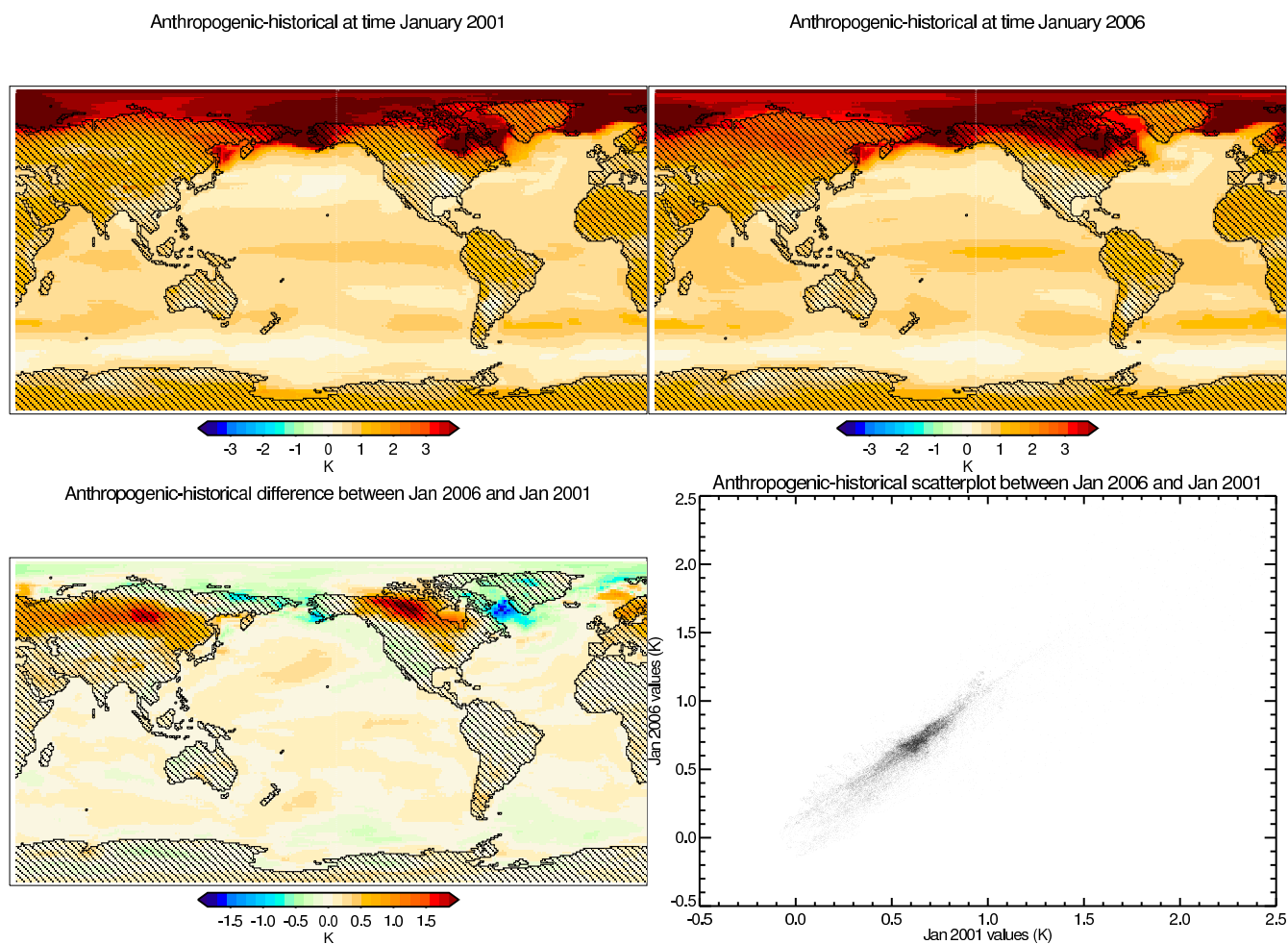


Figure 5: Maps of estimated attributable warming maps for January 2001 (top left), January 2006 (top right) and their difference (bottom left), after application of a 5-year boxcar filter for each calendar month. Land areas are partially masked for clarity. The plot at bottom right plots January 2006 ocean grid boxes against the corresponding January 2001 boxes. More extreme values than 2.5K (from the sea ice edge) have been cropped.

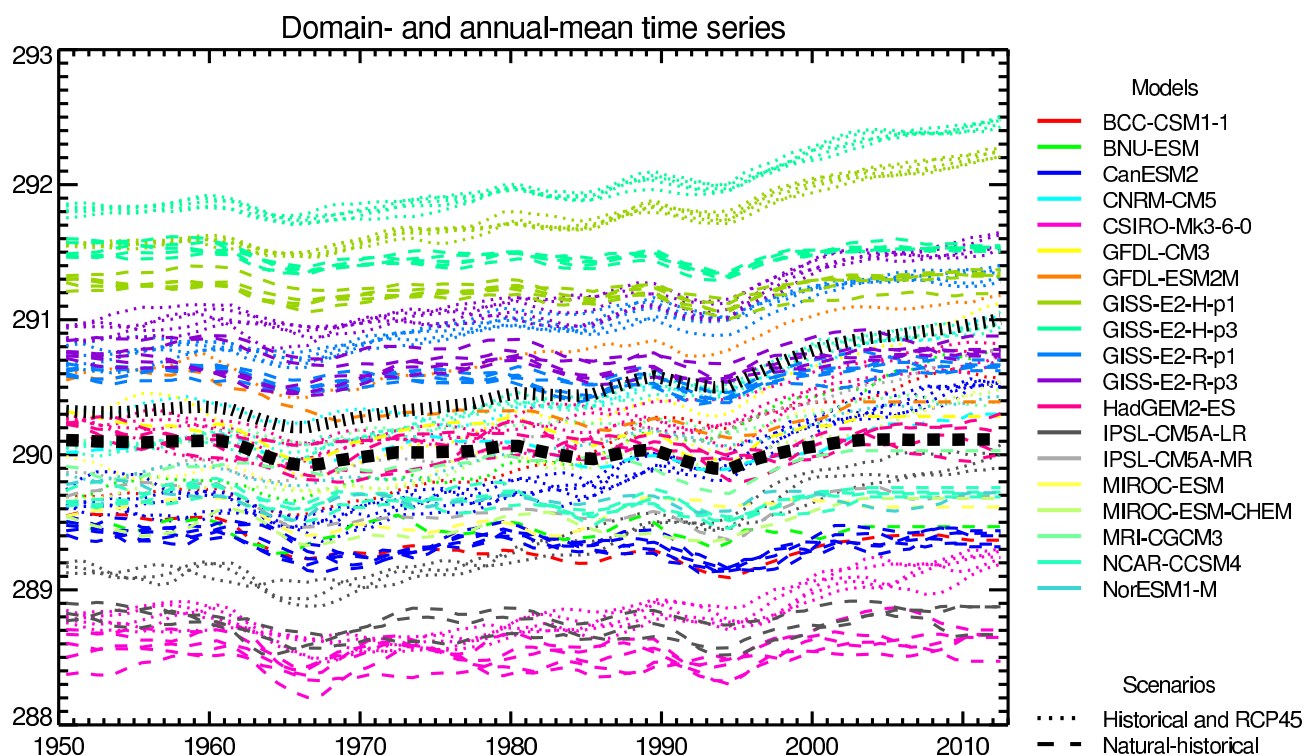


Figure 6: Annual global mean time series of skin temperature from the various CMIP5 simulations used in the calculations, after application of a 5-year boxcar filter for each calendar month. Details of the models and simulations are listed in Table 3. The black lines denote the average across all 51 simulations for each scenario.

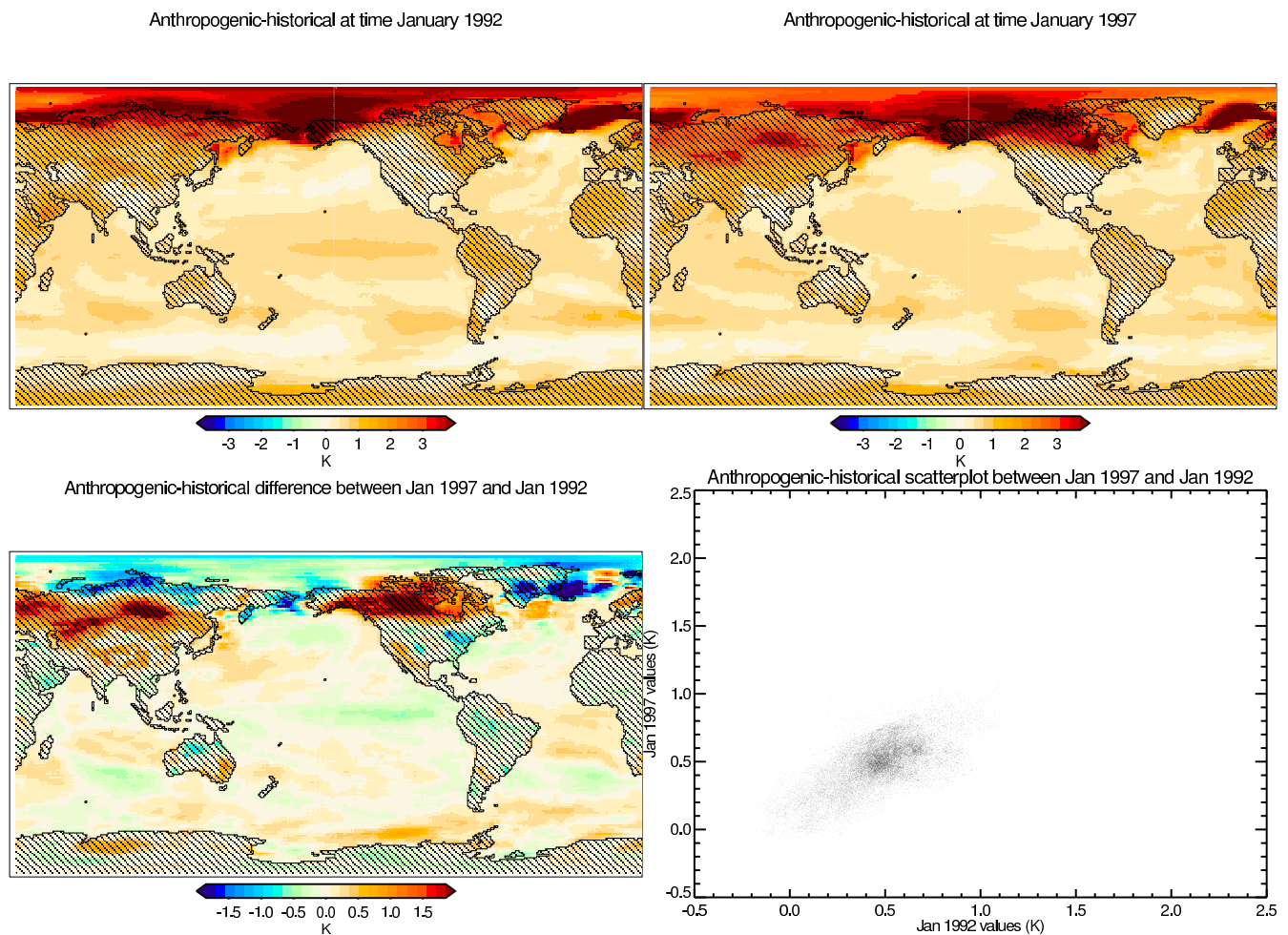


Figure 7: Maps of estimated attributable warming maps for January 1992 (top left), January 1997 (top right) and their difference (bottom left), without any temporal filter applied in the calculation. Land areas are partially masked for clarity. The plot at bottom right plots January 1997 ocean grid boxes against the corresponding January 1992 boxes. More extreme values than 2.5K (from the sea ice edge) have been cropped.

More systematically, Figure 8 shows the root-mean-squared differences between the oceanic attributable warming spatial patterns across different years for each calendar month. The global ocean average has been subtracted from each month before calculation so larger values reflect greater differences between the spatial patterns or different magnitudes of the same pattern, but not a uniform warming. The years following the Agung, El Chichón, and Pinatubo eruptions do not stand out as being noticeably different from other years.

The conclusion therefore is that oceanic surface responses to volcanic eruptions are independent of the responses to anthropogenic forcings. Thus application of a temporal filter, which smooths out the response to volcanic eruptions, does not contaminate attributable warming estimates.

5 Nat-Hist/CMIP5-v1 sea ice coverage

5.1 Applicability of attributable ocean warming estimate

One issue raised in the discussion above concerns the appropriateness of the ocean attributable warming estimates for use in estimating attributable changes in sea ice coverage. Figure 9 shows time series of various temperature measures from the various CMIP5 simulations at a point in the Arctic Ocean. Because they are mostly constrained to the freezing point (defined differently between models), estimation of attributable warming using sea surface temperature is not appropriate. Use of skin temperature or 1.5m near-surface air temperature yields more plausible changes however, with no obvious difference between the two measures (note the vertical ranges differ between panels). The conclusion then is that estimates of the attributable warming pattern using skin temperature can be used as input to a procedure for a procedure estimating attributable changes in sea ice coverage.

5.2 The Pall et al. (2011) approach

Pall et al. (2011) developed an approach to altering sea ice coverage in a manner that is consistent with changes in sea surface temperatures. This method involved determining a simple functional form to the temperature/ice-coverage relationship and modifying ice coverage using this function. Pall et al. (2011) adopted a function of the form:

- Full coverage below the freezing point.
- Coverage between no coverage and full coverage following a linear function anchored to the freezing-point/full-coverage point and fitted to hemispheric observational data for all intermediate-coverage situations. Note this results in different linear functions for either hemisphere. The resulting fits are shown as blue lines in the top left and middle left panels of Figure 10.
- Zero coverage below at temperatures above the zero-coverage intercept of the above linear fit.

We adopt a similar function here except that the intermediate-coverage portion is estimated slightly differently. First we calculate the median temperature in each of 100 ice-coverage bins, and then we fit a line through the freezing-point/full-coverage point and through the median-bin function. The calculations are performed on observed temperature/ice-coverage data over the 2001-2010 period. The resulting functions when the NOAA OI.v2 observational dataset is used are shown as the dashed red lines in the top left and middle left panels of Figure 10. For practical purposes, the Pall et al. (2011) linear fit and this alternative are indistinguishable. Below, this empirical fit is referred to as fSIC(SST).

Given this function, the Pall et al. (2011) algorithm follows the following steps, illustrated by the arrows in the top right and middle right panels of Figure 10, where SST represents sea surface temperature and SIC represents sea ice coverage (falling in the 0 through 1 range), and the “obs” and “nat” subscripts denote the observed data and the Nat-Hist scenario, respectively. dSST refers to the attributable warming estimate. SST_{open} is defined as the point at which $fSIC(SST_{open})=0$.

- If $SIC_{obs}=1$, then $SIC_{nat}=1$, regardless of dSST.

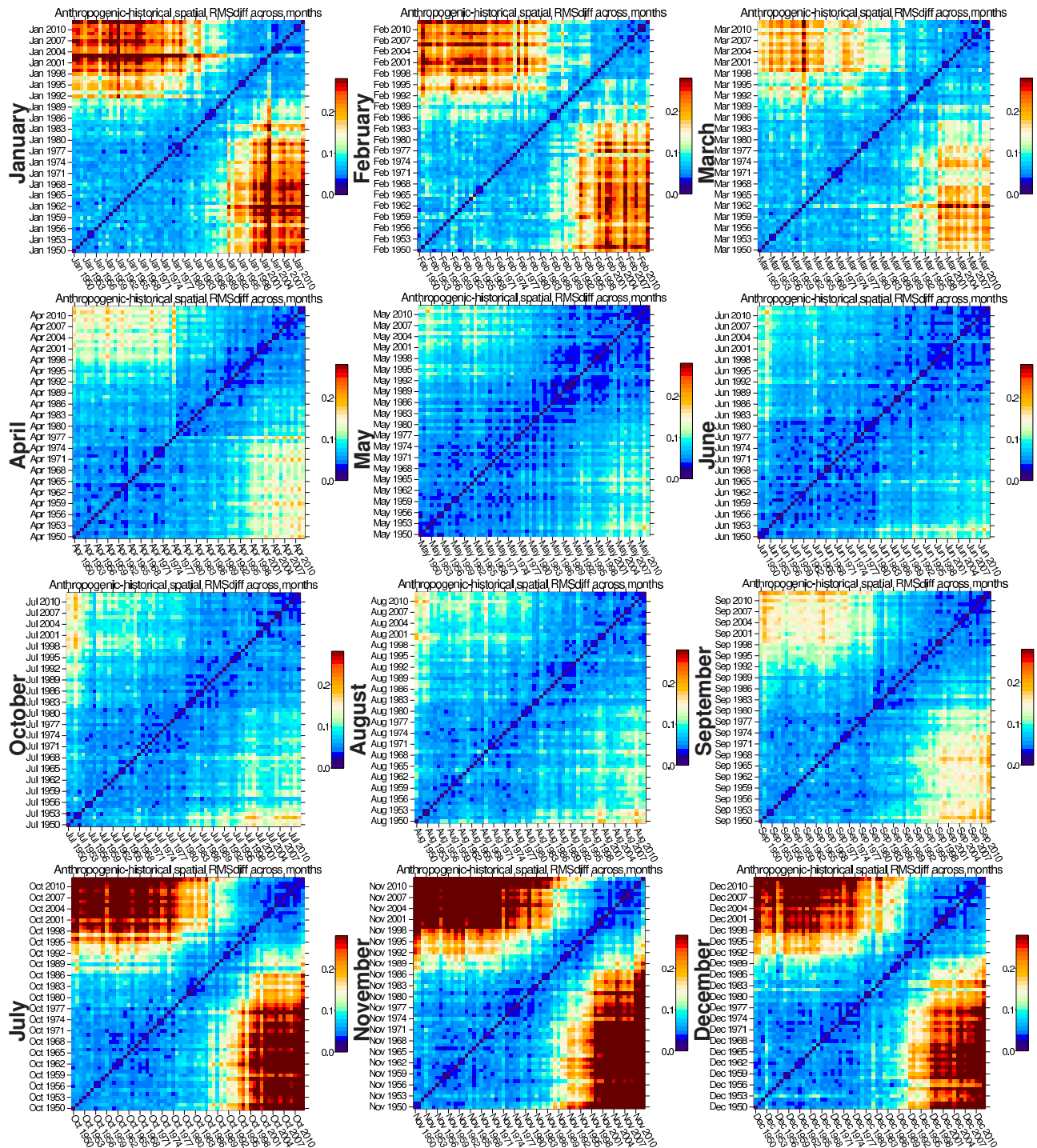


Figure 8: Plot of the root-mean-squared difference of the spatial patterns (spatial anomalies from the global mean) of attributable warming estimates between different years during the 1960-2012 period. No time filters were applied in the calculations behind these plots. Note the smaller differences between the years following 2005 is affected by the repetition of 2005 for later years in the HistoricalNat simulations of some models.

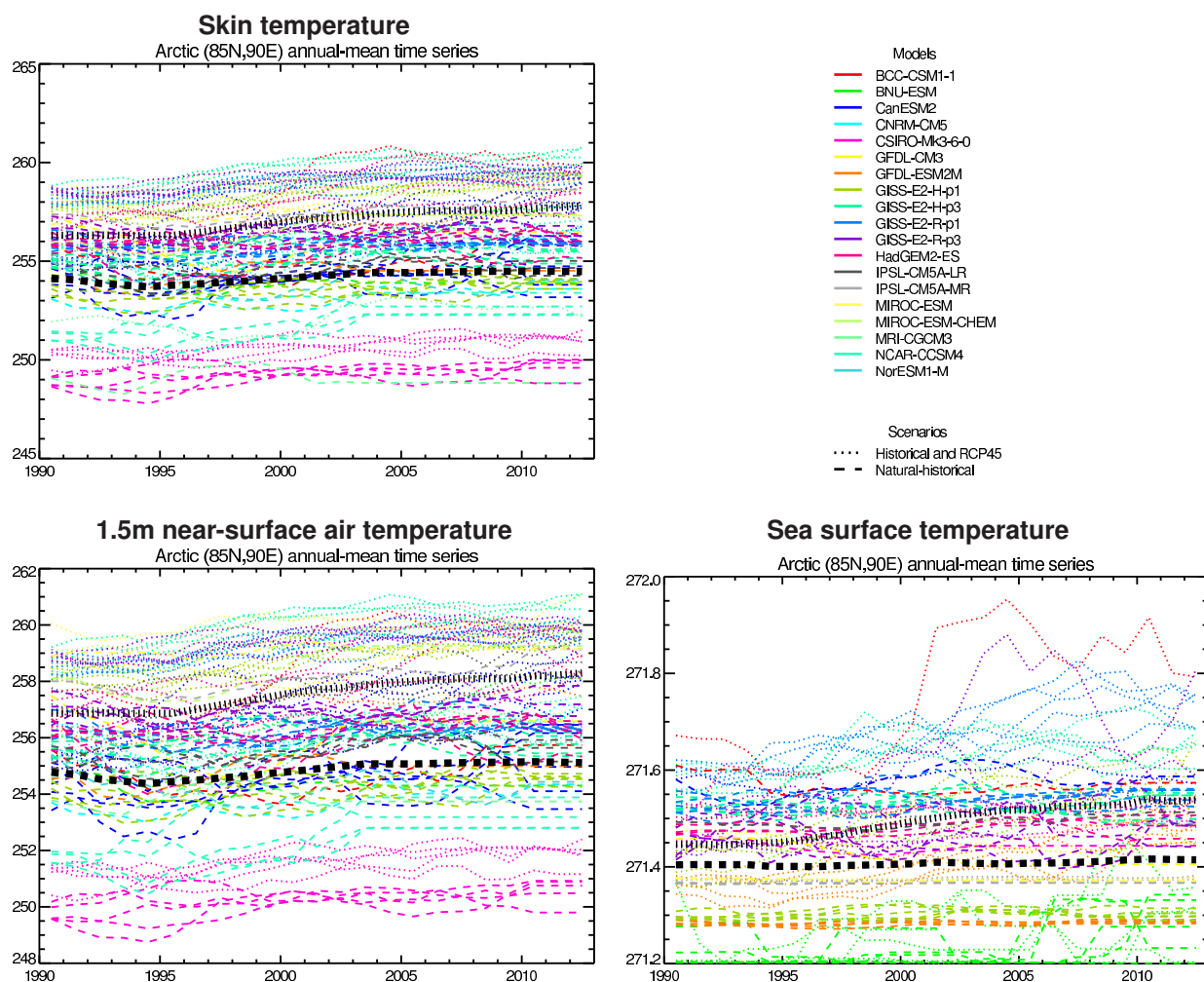


Figure 9: Time series of various temperature measures from the various CMIP5 simulations around 85.5°N, 89.5°E. The black lines denote the average across all 51 simulations for each scenario. A 5-year temporal filter was used in all calculations.

- If $0 < SIC_{obs} < 1$ and $dSST \geq 0$, then $SIC_{nat} = SIC_{obs} + fSIC(-dSST)$, to a maximum of $SIC_{nat} = 1$.
- If $0 < SIC_{obs} < 1$ and $dSST < 0$, then $SIC_{nat} = SIC_{obs} + fSIC(-dSST)$, to a minimum of $SIC_{nat} = 0$.
- If $SIC_{obs} = 0$ and $dSST \leq 0$, then $SIC_{nat} = 0$.
- If $SIC_{obs} = 0$, $dSST > 0$, and $SST_{obs} < SST_{open}$, then $SIC_{nat} = SIC_{obs} + fSIC(-dSST)$, to a maximum of $SIC_{nat} = 1$.
- If $SIC_{obs} = 0$, $dSST > 0$, and $SST_{obs} > SST_{open}$, then $SIC_{nat} = fSIC(-dSST + SST_{obs} - SST_{open})$, to a maximum of $SIC_{nat} = 1$.

One issue with the Pall et al. (2011) algorithm is that it lacks a mechanism for melting full-coverage ice. However, for the Nat-Hist/CMIP5-v1 scenario there is little if any ocean warming occurring in the polar regions, thus here it is not a major problem.

Figure 10 illustrates the methodology and results when applying the Nat-Hist/CMIP5-v1 attributable warming estimate to the NOAA OI.v2 sea surface temperature and sea ice coverage observational product.

6 Acquiring the boundary condition data

The sea surface temperature and sea ice coverage data for running the C20C D&A simulations are available at http://portal.nersc.gov/c20c/input_data/. Various files are provided, with the list increasing through time as per requests for file formats.

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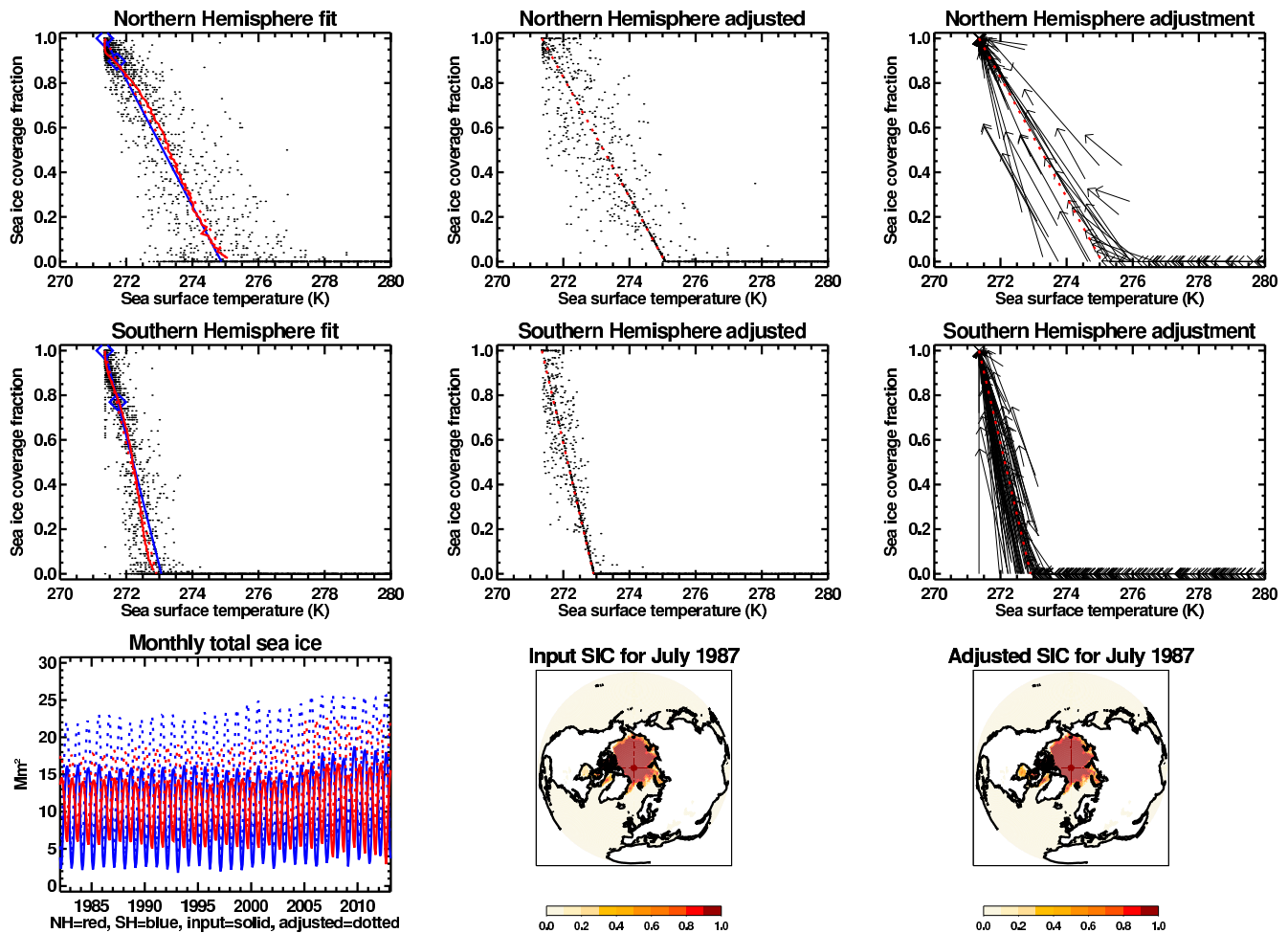


Figure 10: Illustration of the Pall et al. (2011) algorithm for estimating attributable changes in sea ice coverage as implemented for the Nat-Hist/CMIP5-v1 scenario using the NOAA OI.v2 sea surface temperature and sea ice coverage observational product. The top two rows illustrate the mechanism for the Northern Hemisphere (top row) and Southern Hemisphere (bottom row). The left panels show the sea ice coverage and sea surface temperature relationship during the 2001-2010 period (dots), the Pall et al. (2011) linear fit for adjusting ice coverage (blue line), and the function of median temperatures for each coverage bin (solid red line), and the resulting linear fit used for the Nat-Hist/CMIP5-v1 scenario (dashed red line). The middle panels show the new temperature and coverage data after following the algorithms illustrated in the right panels for estimating the Nat-Hist/CMIP5-v1 sea ice coverage. The bottom left panel shows the monthly coverage time series for both hemispheres (North in red, South in blue) as observed for the All-Hist-v1 scenario (solid) and under the Nat-Hist/CMIP5-v1. The two maps illustrate Arctic coverage for May 2011 for the observed All-Hist-v1 scenario (middle) and the Nat-Hist/CMIP5-v1 scenario (right).